Coastal Engineering Technical Note

DEAD-END CHANNEL FLUSHING IN HARBORS

PURPOSE: The purpose of this technical note is to present some design considerations which benefit dead-end channel flushing. Some of these factors can also be used to improve flushing in existing harbors.

INTRODUCTION: Flushing uses the natural energy sources available to remove pollutants and suspended sediments from a waterbody. Construction of dead-end channels should be avoided if possible because they have only one boundary open to flow, thus flushing is limited to this single opening. If it is necessary to build a dead-end channel or deal with an existing dead-end channel, it is crucial to utilize the energy available for efficient flushing. Energy losses (such as losses due to roughness elements, bends, changes in cross-sectional area, canal size, and water velocity) should be avoided unless they create mixing which aids in flushing.

ENERGY SOURCE CONSIDERATIONS: The energy available for flushing comes from tides and wind. The limited amount of tidal energy available causes movement of water into and out of the channel area, thus flushing out some pollutants. Efficient use of tidal energy depends on channel geometry, as discussed in later paragraphs.

The wind blowing along the length of dead-end channels causes the upper layers of the waterbody to move in the direction of the prevailing wind, and bottom water movement is opposite to the prevailing wind direction (Figure 1). Vertical circulation occurring at the dead end results in vertical mixing which aids in flushing.

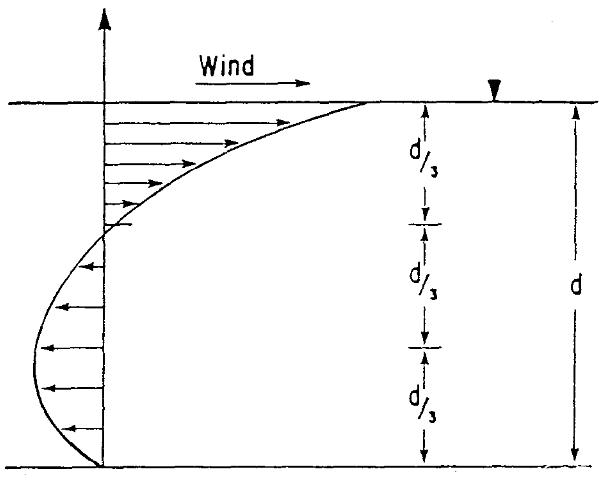

Figure 1. Theoretical Vertical Velocity Profile

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Circulation occurs whether the prevailing wind is toward the dead end or toward the open end, but the latter is preferred. When the prevailing wind is toward the dead end, the surface movement carries debris into the channel which may settle out and create an anaerobic (oxygen-deprived) condition; however, if the wind is of sufficient strength and duration, it will cause enough circulation to flush settling debris to the open end and accumulate floating debris at the dead end. This accumulation of debris indicates circulation is occurring and flushing is adequate. Evenly distributed floating debris would indicate poor circulation and therefore poor flushing. The "wind toward the dead-end" design's dependency on strong wind makes it less desirable than the "wind toward the open-end" design.

If a specific project requires flushing rates to determine water quality parameters, then physical or numerical models may be used. It should be noted that the circulation needed to adequately flush channels also provides a means of keeping sediment in motion, thereby reducing shoaling in the channel.

GEOMETRIC CONSIDERATIONS: The geometric design should be such that energy losses are minimized, with the exception of the energy that is lost in creating turbulent eddies. Turbulence promotes mixing which aids in flushing unstratified channels.

(1) Depth. Flushing by tidal action becomes inadequate beyond a depth of approximately 12 feet mean sea level (msl), based on a 2- to 5-foot tidal range. The potential energy of the tides is not sufficient to create the movement needed to flush the bottom area below this depth. Sediments and organics may accumulate, and an anaerobic condition can develop.

Dredge holes in a channel bed should be avoided because they are difficult to flush. Without sufficient circulation, deep depressions can trap sediments, organics, and water, resulting in anaerobic pits.

Minimum depth of a navigation channel is a function of the maximum draft of boats expected to use the harbor. The channel depth should be sufficient for boats to operate safely. Typically, depths should not be less than about -5 feet msl.

Shallow sections (sills) in a channel create blocks in the circulation loop which decrease the circulation rate and cause a decrease in the flushing; therefore, sediments and organics become trapped and settle out of suspension.

A shallow area may also create a navigational hazard. Discontinuities in the channel bottom, such as dredge holes or sills, decrease circulation and should therefore be eliminated.

(2) Width. As the width at the water surface increases, the wind has more surface to blow over, leading to improved circulation and better flushing. A greater surface area also provides a larger oxygen transfer surface.

(3) Channel cross section. The width of the deepest section in a trapezoidal channel (W_1--see Figure 2) must be large enough for the anticipated boat traffic to safely navigate. Typical existing bottom widths range from 50 to 100 feet. The bank slope (S) must be stable against both material failure (slump) and erosion. The cross section determined by these width, depth, and slope requirements creates a large channel volume, $\frac{D}{2}(W_1 + W_2)L$, relative to the tidal prism (surface area times tidal range) $\frac{t}{2}(W_2 + W_3)L$ for tidal ranges of less than 2 feet. The resulting low-flow velocity is more likely to cause deposition than bank erosion, and in this case, the main design concern is bank stability against slumping due to material failure. However, if the flow is great enough due to the addition of other sources of water (such as stormwater inflow, creek inflow, large tidal range, or water from a harbor or basin at the dead end), velocities large enough to cause bank erosion may occur. In this case, the cross section should be designed to help control the erosion.

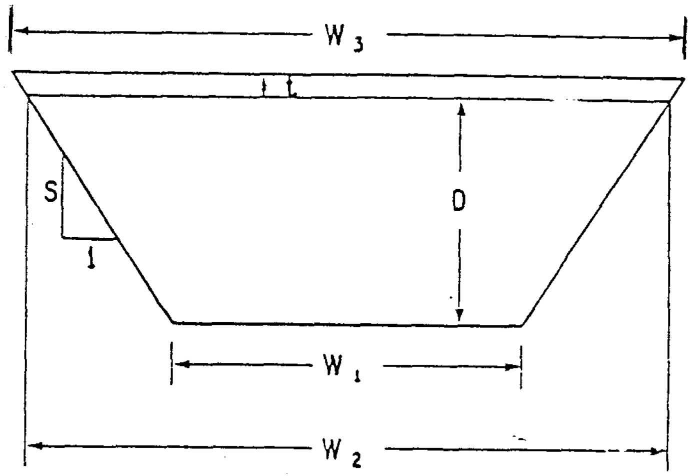

Figure 2. Channel Cross Section

(4) Banks. For a given cross-sectional area, sloping banks provide better channel stability, a larger tidal prism (which results in greater circulation), more surface area for oxygen transfer and for the wind to blow over, and improved navigation for smaller boats than do vertical walls. Smaller boats with shallow drafts are able to navigate on part of the sloped section, but deeper draft boats are limited to the deep midsection. Sloped banks require more land; however, the improved flushing, bank stability, lower maintenance requirements, and the aesthetically pleasing channel should increase

the property value in this area. Vegetation on sloped banks provides soil stability, dissipates boat wake energy, and creates a self-purification system through biological action (i.e., provides its own oxygen).

Some advantages of vertical banks are that the amount of land required for construction is minimized, the channel will be navigable over the entire width, and boat moorings will be more accessible.

Vertical walls (bulkheads) may be used to hold back fill, but they are susceptible to erosion at the toe due to boat wakes and land runoff. Therefore, maintenance costs may be high. Boat wakes reflecting off vertical banks may lead to dangerous navigational conditions.

It is recommended that vertical bulkheads be avoided whenever possible. If vertical bulkheads are necessary, the bank should transition gradually from sloped to vertical. One might consider putting sloped banks directly across the channel from any required bulkheads.

(5) Transitions. Changes in channel dimensions should be constructed to occur at a gradual transition in order to minimize energy loss.

(6) Boundaries. Boundary conditions (walls, bed, dead end) should be designed to create and sustain turbulent eddies which aid in mixing and flushing unstratified channels. The circular water movement (i.e., eddy current) is created when the main stream passes an obstruction or when adjacent currents flow in opposite directions.

(7) Bends. Meandering channels create spiral flow which produces movement of water in a direction other than the principal flow direction. These secondary currents create vertical mixing which aids in flushing.

(8) Roughness elements. Large rectangular obstructions placed on channel walls (see Figure 3) create (a) a meandering effect which leads to vertical mixing and (b) turbulent eddies which aid in mixing and flushing. Local flushing increases with increased roughness element size, but energy loss also becomes significant. Rounded roughness elements on the channel bed (see Figure 4) also create meandering which results in mixing but to a somewhat lesser extent than the rectangular obstructions. Energy loss on the smoother surface is negligible. Therefore, the optimum design is a trade-off between creating mixing for flushing and minimizing energy loss. Some shoaling may occur adjacent to the roughness elements if a static condition is created.

(9) Orientation. The channel should be oriented in the direction of the prevailing wind in order to maximize flushing.

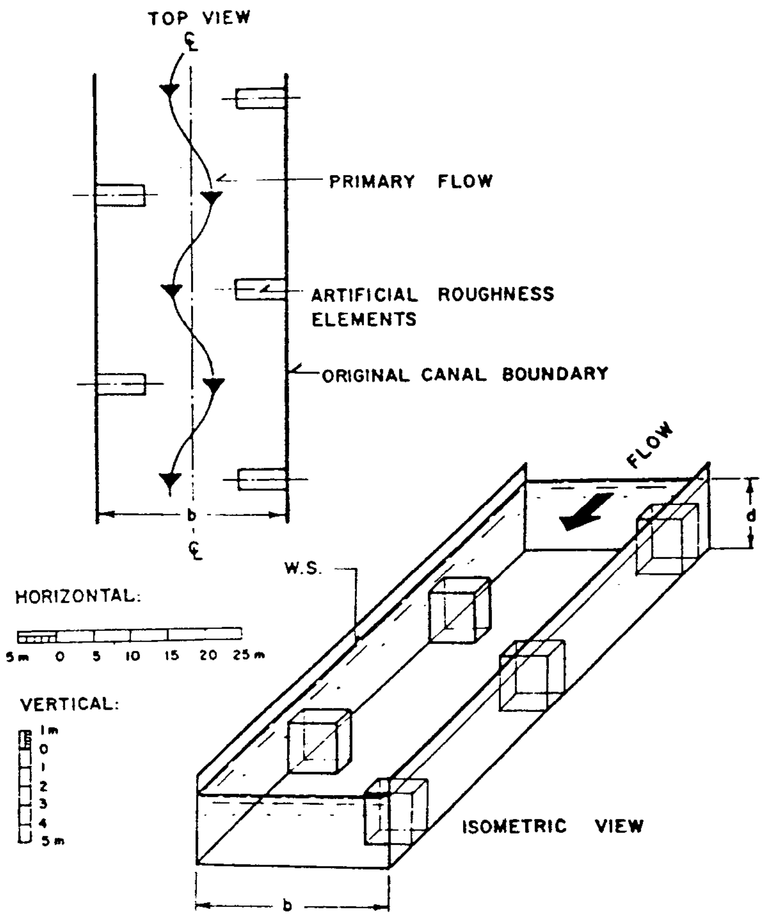

Figure 3. Placement of Artificial Roughness Elements (from MORRIS, 1981

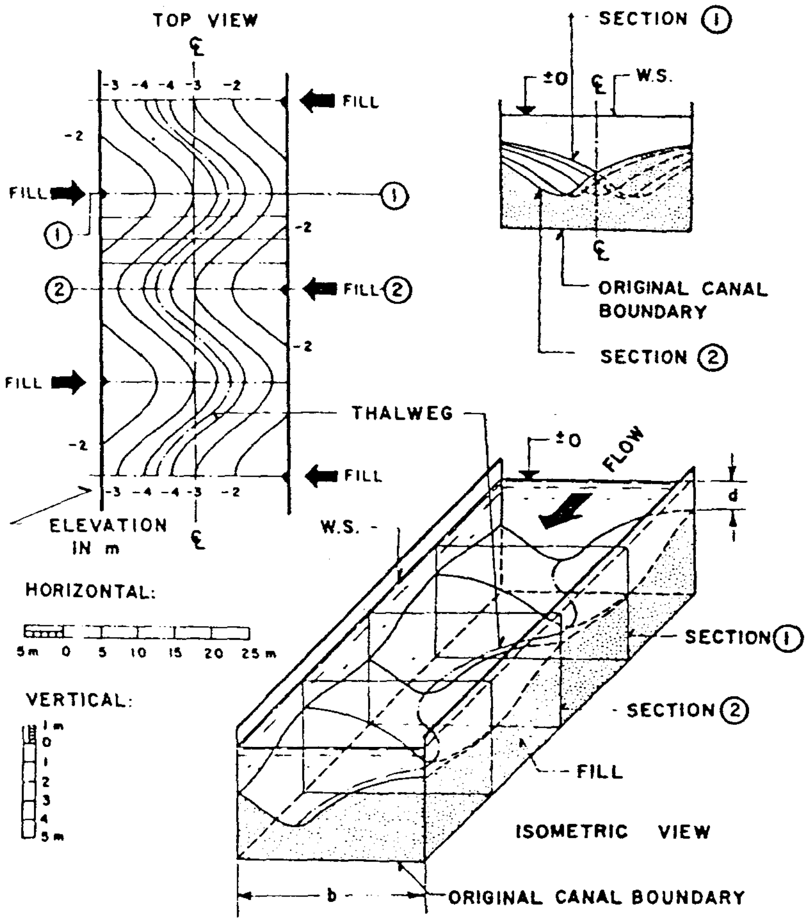

Figure 4. Placement of Fill to Create Meandering Flow (from MORRIS, 1981)

(10) Length. A longer channel requires additional energy in order to create the circulation needed to adequately flush out pollutants and keep sediments in suspension. Without sufficient energy, pollutants will not flush effectively and the accumulation of sediments will create a need for dredging. A typical range for channel length is 1,500 to 10,000 feet.

SALINITY GRADIENT: If a dead-end channel has poor circulation, salinity will increase due to evaporation and a density gradient (denser salt water concentrated beneath lighter fresh water) will result. A large density gradient leads to stratification which may reduce vertical diffusion and mixing. Thus, flushing of the channel is reduced.

A density gradient does cause horizontal flow and some circulation within each layer, but the reduced vertical mixing hinders flushing.

Limiting channel length may prevent a severe density gradient from forming.

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REFERENCES:

MORRIS, F-W., "Residential Canals and Canal Networks: Design and Evaluation," Report No. 43, Florida Sea Current College Program, Dec. 1981.

CHRISTENSEN, B.A., MORRIS, F.W., and WALTON, R., "Hydrodynamic Factors involved in Finger Canal and Borrow Lake Flushing in Florida's Coastal Zone," Report HY-7801, University of Florida, August 1978 (report to FSGC program).